Comparison of gradient induced heating around an active implantable medical device

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Introduction: Due to sophisticated high field MR and diversity of MR imaging sequence, it is important to consider mutual effect between implantable medical device and magnetic field. The effects were displacement force, torque, heating, artifacts, vibration of device, the influence of exogenous potential and rectification according to ASTM (American Society for Testing and Materials) [1-4] and IEC (International Electro technical) [5]. Heating effect by gradient magnetic field was considered smaller than the effect by RF field. However there were not the clear safety standard of effects on the nervous system but heating. In this study, we performed basic analysis of the heating by gradient magnetic field in a 34-years-old male adult model (Duke) of IT'IS Virtual Population with a MR compatible cardiac pacemaker.

Methods and materials: Figure 1 shows a Numerical modeling, based on the low frequency solver, was used to evaluate the temperature rises by gradient magnetic field. In this numerical investigation, the simulation procedure consists following parts: (1) set low frequency (LF) current source, (2) perform the electromagnetic simulations with low frequency solver, (3) perform the thermal simulations with the steady state solver.

(1) LF current source: Set the center of a pair of Helmholtz coils (radius: 1.5m) as LF current source to head of the human model. For example, gradient magnetic fields of the EPI (Echo Planar Imaging) sequence were quickly switched over 25mT/m. In this study, slew late of the gradient magnetic field was set 40mT/m. The waveform of the gradient magnetic field varied depending on the sequence defined as a sine wave.

(2) EM-simulation: Performed at each frequency (250, 500, 750, 1000, 1750, 2500Hz) with low frequency solver (Type: Magneto Quasi-Static) using SEMCADX (Schmid & Partner Engineering AG), to calculate the specific absorption rate (SAR).

(3) Thermal simulation: The each result of EM-simulation were used to Thermal simulation. The steady state solver was used to analyze the temperature of the steady state. Initial temperature was set to 0℃. Table 1 shows boundary conditions of simulation.

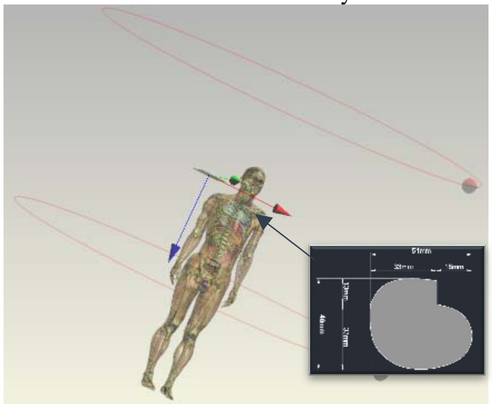

Figure 1: Experimental model setup comprising of a pair of Helmholtz coils and human model (Duke) with a cardiac pacemaker (Ti-6Al-4V)

Table 1: Simulation conditions of Boundaries

	Outside T	Heat Transfer	Heat Flux	Boundary type
Tissue -> External boundaries	0	6	0	Mixed
Tissue -> Internal boundaries	0	0	0	Neumann
Tissue -> Blood interface	0	0	0	Dirichlet

Result: Figure 2 shows maximum temperatures of whole body and periphery of the device for each frequency. The maximum temperature increased in intensity with frequency. And Figure 3 shows temperature distribution at 2500Hz of whole body and periphery of the pacemaker. Simulation procedures were performed on Personal Computer (Windows 7, 64-bit, CPU: Intel(R) Core(TM) i7, 2.5GHz x 8, 32GByte RAM, GeForce GTX 560M 4GByte GRAM). Averages of simulation time were eight hours and six minutes for EM-simulation and one hour and eight minutes for thermal simulation. Temperature was higher near the center of the element of Helmholtz coil. The temperature was on the distance from the center of Helmholtz coil. In this simulation, the maximum temperature around the pacemaker was 1.74e-04℃ and in whole body was 6.83e-03℃ at 1000Hz. The temperature increases in correlation to the frequency.

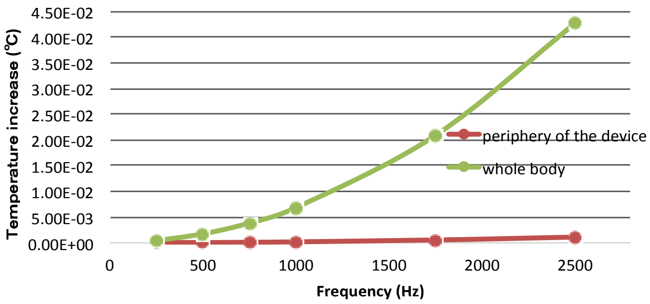

Figure 2 Maximum temperature of whole body and periphery of the device.

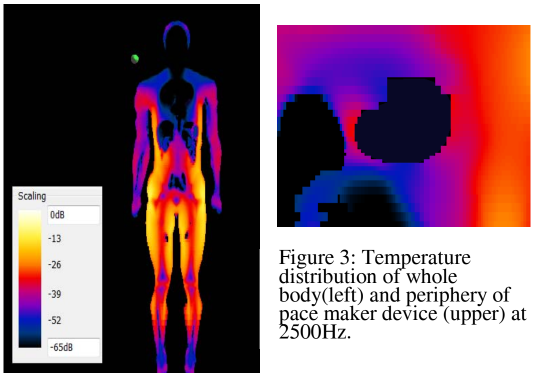

Figure 3: Temperature distribution of whole body(left) and periphery of pace maker device (upper) at 2500Hz.

Discussion and Conclusions: Temperature distribution of whole body with implantable medical device by the low frequency band of the gradient magnetic field generated by the Helmholtz coils were calculated by low frequency solver and thermal simulation with steady state solver. The temperature increase at periphery of a cardiac pacemaker was very low compared with the maximum temperature on human body. The results showed that no substantial risk for heating with low frequency gradient magnetic field.

References

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